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THE MAGNITUDE EQUATION IN STAR TRANSITS.

By R. H. Tucker.

In accordance with previous practice, the effect of magnitude equation, or the influence of the brightness of a star upon the transit recorded by chronograph, has been recently investigated again here. The observations were made on five nights, in the month of August, and the results will be used to determine and to confirm the correction that will be applied to the transits of stars observed in the present program of meridian-circle work, which includes about four thousand observations.

The usual result of such determinations is shown in this series; nearly all observers who have investigated the correction are found to have recorded faint stars later than bright stars. The effect is determined by screening the object-glass for some transits of the brighter class of stars, and comparing the recorded transits with those of the same stars, when observed full brightness. The screen was applied with the help of volunteer assistants, as in the earlier series. The screen used in this series reduces the brightness by nearly four units of magnitude (3.95 ± 0.05), the reduction being derived from the difference between the full brightness and the estimated magnitude when the screen has been applied. For the magnitudes of the stars, the Harvard photometric magnitudes have been adopted, tho these do not differ much from the values given in the *Berliner Jahrbuch,* the photometric scale being 0.1 fainter for the mean, with an average difference of ± 0.15 between the two scales. The stars selected range in brightness from 0.1 to 6.3, but the reduction due to the screen appears to be less for the faintest stars observed than for the brighter classes. Up to third and fourth magnitudes, the reduction is estimated in excess of four units; while the stars of fifth and sixth magnitudes are reduced by less than four units, according to the estimates made at the time of transit. This apparent discordance may be due to a difference between the adopted visual scale of magnitudes, and a scale that would be exactly photometric, as the visual scale was really intended to be. The visual scale, used by meridian-circle observers, was practically formed earlier than the extensive employment of photometric measures. My estimates of the magnitudes of the screened stars are in accord with my regular observing scale, which is based upon long experience in the estimation of faint telescopic stars. It is very exactly the scale of the *Durchmusterung*, which has been continued in the great series of the *Gesellschaft* zone catalogues, and is in fact consistently used by all meridian-circle observers, who make estimates of the magnitudes of the faint stars.

Some of the recent photometric measures at Harvard College Observatory and the corresponding discussions and conclusions give a similar indication of a systematic difference between the photometric and visual scales, for the fainter classes of stars. That is, the typical visual ninth-magnitude star would be classed, photometrically, as brighter. And the visual tenth magnitude would be photometrically brighter than the tenth, by an amount in excess of the difference at ninth magnitude. The scales are generally in fair accord up to seventh magnitude; and, at eighth magnitude, some perceptible systematic difference is to be noted.

The screen estimates thus give an indication of a systematic correction to the visual scale, for faint stars, if the effect of screening the bright stars is assumed to be photometrically the same for all classes of brilliancy. It is worth while repeating the statement that the visual scale is intended to reproduce a true gradation in brilliancy; two and a half times the light, for each difference of a unit of magnitude. This was originally derived from the naked-eye estimates of the bright stars, down to sixth magnitude; and the endeavor of telescopic observers was to carry this same scale down to the ninth and tenth magnitudes. Photometric measures are based upon this same gradation, extending the adopted visual scale down to fainter classes, and comparing and co-ordinating the whole mass of stars so as to get, if possible, more exact estimates of every individual star. The type of ninth-magnitude star has been so consistently adopted by meridian-circle observers, based largely upon the magnitudes of the *Durchmusterung*, that it would be difficult to change this estimate in practice, even if the magnitudes of the existing star catalogs could be adjusted to a scale more in conformity with late photometric measures.

In its effect upon the present results of magnitude equation, this possible discordance does not produce errors of any serious amount, for the total effect of the screen upon transits, derived for stars of estimated brightness, is in accord with the usual visual scale for stars of those types. In dividing the total effect by the reduction due to the screen, a small uncertainty in the reduction per unit of magnitude may be introduced; but there already exists some doubt as to whether the reduction is the same for some observers at all points of the scale. That is, for some observers the difference in transits between a second and sixth magnitude may be quite different from the difference in transits between a fifth and a ninth magnitude. This present series has been tested for such a variation, but has been found to give fairly uniform values of the magnitude equation, for the different classes of bright stars reduced by the screen.

These values are: a difference of $0^s.027$ for south stars, or $0^s.007$ per unit of magnitude; and $0^s.031$ for stars north of the zenith, or $0^s.008$ per unit of magnitude. Twenty-four stars south of the zenith were used, and twelve stars north of the zenith, on the same five nights. By using five nights, the differential values can be taken out in reverse order for the pairs of adjoining nights, giving four determinations of magnitude equation, well balanced in respect to accidental effects of combination. The five nights, then, give a weight of sixty determinations south of the zenith, and a weight of thirty north. The probable error of a single determination of the full difference due to screen is $\pm 0^s.030$ for south stars and $\pm 0^s.026 \sec \delta$ for north stars. The probable error of the mean result does not much exceed $\pm 0^s.004$ in either case, and the probable error per unit of magnitude is $\pm 0^s.001 \sec \delta$. The values from stars on both sides of the zenith are nearly the same, tho some variation might be anticipated, and in fact is often found to exist, for various observers.

Explanation of a variation would be involved in the general explanation of the cause of the correction for magnitude equation. If there is a difference in the reaction time, depending upon the brightness of the star, the difference may be influenced by the condition of the direction of the motion of the star in transit. Facing south, a star appears to move from right to left, in an inverting telescope; while, facing north, a star appears to transit from left to right.

My own habit of recording chronographic transits is to touch the key when the star appears to be bisected by the thread, in place of trying to have the touch occur at the instant of bisection. The record made by my finger will always be a minute amount late of true bisection, due to the transmission of the visual phenomenon to brain, and, thence, to the finger. It is like shooting flying fowl, with which chronographic records have been often compared. By endeavoring to make the record simultaneous with the bisection, the flying bird would be hit by the shot; in the other method we should miss the bird by shooting regularly behind it; but my own opinion is that a nearly constant error is introduced by the second method, and that the differential error is thus smaller, the differential error being the important one in star determinations in general. The bisection I believe is accurately noted by the eye, for faint and bright stars, and the impression is correctly conveyed to brain and finger; but the impression is more intense for the brighter stars, and the reaction time is consequently shorter. This would account for the effect known as magnitude equation, an effect which belongs more exactly to the domain of the psychologist than to that of the observer of visible phenomena; but when we can determine and correct for the effect, the real cause of the difference may be left to future investigation and discussion. The correction is small, a few hundredths of a second in the total, for most observers; and if we endeavored to correct our observing habits for such small amounts, we should certainly fail, and would probably produce very uneven and unreliable observations. It is one of the cases when an error of known amount can be best left alone, since it should eventually be practically constant for a trained observer, and the correction can be derived, and can be applied to results at any time, perhaps even many years later, in a discussion of the published results.

Except for some diffraction rays, for the very brightest stars, which do not interfere with precise observations of the central image, the image of a screened star is quite exactly like that of a star of fainter class. The screen is made of very fine wire netting, most carefully constructed for uniformity of spacing, and four thicknesses are used in the screen that gives a reduction of about four units of the magnitude scale.

To illustrate the consistency of the magnitude equation, and for a record of the results to date, the earlier determinations are tabulated here. They include those made at the San Luis Observatory of the Carnegie Institution, in the years 1909 and 1910, when the observations were taken with the meridian circle belonging to the Dudley Observatory at Albany, the object glass of which is eight inches, while ours is 6.4 inches, at Lick. At the southern station, in the Argentine Republic, it is to be noted that the clock stars and the rapidly moving stars in general were north, while here the same class of stars are south of the zenith. In the larger and older instrument, there are three sets of transit threads, of nine wires each, so that a determination of magnitude equation can be made at one transit, by screening either one or two of the sets. With our single group of threads, it requires the comparison of results upon two nights to give a determination. This present series is the second one taken since my return, and such a record of alternation with two instruments, and with the variety of conditions, can not often be obtained. Notwithstanding some variations in the results for different years, the magnitude equation is evidently nearly constant, with a slight difference in effect depending upon the direction of motion.

LICK OBSERVATORY MERIDIAN CIRCLE.

South stars—

Year.	No.	Mag. Eq.
1896	75	$-0^{s}.009$
1898	60	$-0\ .006$
1902	48	$-0\ .006$
1907	49	$-0\ .010$
1911	45	$-0\ .010$
1914	60	$-0\ .007$
Mean		$-0^{s}.008$

North stars—		
1907	91	—0^{s}.025
1911	50	—0 .016
1914	30	—0 .008
Mean		—0^{s}.016

SAN LUIS OBSERVATORY.

South stars	1909-1910	100	—0^{s}.010
North stars	1909-1910	300	—0 .015

A transit micrometer, one of the advantages of which is the claim that the magnitude equation is eliminated, has been ordered for the Lick Observatory. A test of the claim of freedom from this effect will be to observe for the magnitude equation, precisely as has been done with the present method. The European war will prevent the dispatch of this construction for our use at the time specified, and it may be some length of time before we can receive it and put it into service. The fact that my own magnitude equation is so well determined, for chronograph transits in the usual way, will aid in a definite test of the new construction. It would not be enough, for instance, to show simply that no effect is left when the transit micrometer is used; it is necessary to show that the effect existed, for a special observer, without the use of the traveling thread.

For illustration of the variety of magnitude equation, for separate observers, there are tabulated below the condensed results for the five observers who did transit work at San Luis, taken from the *Carnegie Year Book*, 1911, page 160:—

	North.	South.
R. H. Tucker	—0^{s}.015	—0^{s}.010
A. J. Roy	—0 .015	—0 .003
W. B. Varnum	—0 .010	—0 .003
M. L. Zimmer	—0 .011	—0 .008
R. F. Sanford	—0 .005	—0 .010
Means	—0^{s}.011	—0^{s}.007

August 31, 1914.